

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
REQUEST FOR FILING NATIONAL PATENT APPLICATION

Under 35 USC 111(a) and Rule 53(b)

PATENT APPLICATION

Asst. Commissioner of Patents  
Washington, D.C. 20231

WITH SIGNED DECLARATION

NONPROVISIONAL  
NON REISSUE  
NON PCT NAT PHASE

jc644 U.S. PTO



Sir:

03/10/00

Herewith is the PATENT APPLICATION of  
Inventor(s): SAWAZAKI et al.

jc675 U.S. PTO  
09/52832  
03/10/00

Title GROUP III NITRIDE COMPOUND SEMICONDUCTOR  
LIGHT-EMITTING DEVICE

Atty. Dkt.: PM 257760  
M#

T36-120877M/KOH  
Client Ref

including:

Date: March 10, 2000

1. Specification: 15 pages (only spec. and claims) 2. ☐ Specification in non-English language  
3. Declaration ☒ Original ☐ Facsimile/Copy ☒ Abstract 1 page(s); 6 numbered claims  
4. ☒ Drawings: 2 sheet(s) ☐ informal; ☒ formal of size: ☒ A4 ☐ 11"  
5. ☐ See top first page re prior Provisional, National or International application(s). ("X" box only if info is there and do not complete corresponding item 5 or 6). (Prior M# SN )  
6. **AMEND the specification** please by inserting before the first line: -- This is a ☐ Continuation-in-Part  
☐ Divisional ☐ Continuation ☐ Substitute Application (MPEP 201.09) of:  
6(a) ☐ National Appln. No. / filed . (M# )  
6(b) ☐ International Appln. No. filed  
7. ☐ **AMEND the specification** by inserting before the first line: -- This application claims the benefit of U.S.  
Provisional Application No. 60/ , filed . --  
8. ☒ Attached is an assignment and cover sheet. Please return the recorded assignment to the undersigned.  
9. ☐ Prior application is assigned to

by Assignment recorded Reel Frame

10. **FOREIGN** priority is claimed under 35 USC 119(a)-(d)/365(b) based on filing in JAPAN

11. (country)

Application No.	Filing Date	Application No.	Filing Date
(1) 11-090719	March 31, 1999	(2)	
(3)		(4)	
(5)		(6)	
(7)		(8)	
(9)		(10)	

12. (No.) Certified copy (copies): ☐ attached; ☐ previously filed (date)  
in U.S. Application No. / filed on

13. ☐ Attached: \_\_\_\_\_ (No.) Verified Statement(s) establishing "small entity" status under Rules 9 & 27.
14. **DOMESTIC/INTERNATIONAL** priority is claimed under 35 USC 119(e)/120/365(c) based on the following provisional, nonprovisional and/or PCT international application(s):

Application No.	Filing Date	Application No.	Filing Date
(1)		(4)	
(2)		(5)	
(3)		(6)	

15. ☐ This application is being filed under Rule 53(b)(2) since an inventor is named in the enclosed Declaration who was not named in the prior application.
16. ☒ Attached: Form PTO-1449 and cited references
17. ☐ Preliminary Amendment:

**THE FOLLOWING FILING FEE IS BASED ON CLAIMS AS FILED LESS ANY ABOVE CANCELLED**

				Large/Small Entity		Fee Code
18. Basic Filing Fee				\$690/\$345	\$690	101/201
19. Total Effective Claims	6	minus 20 =	*0	x \$18/\$9 =	+ 0	103/203
20. Independent Claims	1	minus 3 =	*0	x \$78/\$39 =	+ 0	102/202
*If answer is zero or less, enter "0"						
21. If any proper multiple dependent claim (ignore improper) is present, add (Leave this line blank if this is a reissue application)				+ \$260/\$130	+ 0	104/204
22.	<b>TOTAL FILING FEE ENCLOSED =</b>				<b>\$690</b>	
23. If "non-English" box 2 is X'd, add Rule 17(k) processing fee				+ \$130	+ 0	139
24. If "assignment" box 8 is X'd, add recording fee				+ \$40	+ 40	581
25. <input type="checkbox"/> Attached is a Petition/Fee under Rule No.				+ \$130	+ 0	122
26.	<b>TOTAL FEE ENCLOSED =</b>				<b>\$730</b>	

Our Deposit Account No. 03-3975

Our Order No. 51273      257760

C#

M#

**CHARGE STATEMENT:** The Commissioner is hereby authorized to charge any fee specifically authorized hereafter, or any missing or insufficient fee(s) filed, or asserted to be filed, or which should have been filed herewith or concerning any paper filed hereafter, and which may be required under Rules 16-18 (missing or insufficient fee only) now or hereafter relative to this application and the resulting Official document under Rule 20, or credit any overpayment, to our Account/Order Nos. shown above for which purpose a duplicate copy of this sheet is attached.

**This CHARGE STATEMENT does not authorize charge of the issue fee until/unless an issue fee transmittal form is filed.**

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NOTE: File in duplicate with 2 post card receipts (PAT-103) & attachments

# APPLICATION UNDER UNITED STATES PATENT LAWS

Atty. Dkt. No. PM 257760  
(M#)

Invention: GROUP III NITRIDE COMPOUND SEMICONDUCTOR LIGHT-EMITTING DEVICE

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This is a:

- ☐ Provisional Application
- ☒ Regular Utility Application
- ☐ Continuing Application
- ☐ PCT National Phase Application
- ☐ Design Application
- ☐ Reissue Application
- ☐ Plant Application
- ☐ Substitute Specification

Sub. Spec Filed  
in App. No.          /         

## SPECIFICATION

# GROUP III NITRIDE COMPOUND SEMICONDUCTOR LIGHT-EMITTING DEVICE

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

5       The present invention relates to a group III nitride compound semiconductor light-emitting device of high light intensity.

10       The present application is based on Japanese Patent Application No. Hei. 11-90719, which is incorporated herein by reference.

### 2. Description of the Related Art

15       Fig. 2 is a typical sectional view showing a structure of a group III nitride compound semiconductor light-emitting device 200 according to the conventional art.

20       The group III nitride compound semiconductor light-emitting device 200 is considered as a representative of conventional-art light-emitting devices of the type having layers of group III nitride semiconductors laminated on a substrate.

25       The group III nitride compound semiconductor light-emitting device 200 comprises a sapphire substrate 11 as a substrate, a buffer layer 12 of aluminum nitride (AlN) laminated on the sapphire substrate 11, an  $n^+$  layer 13 of a high carrier density formed of GaN doped with silicon (Si) and laminated on the buffer layer 12, an intermediate layer 14 laminated on the  $n^+$  layer 13, an n-type clad layer 15 of GaN laminated on the intermediate layer 14, a light-emitting layer 16 of a multilayer quantum well structure (MQW) laminated on the n-type clad layer

15 and composed of alternately laminated well layers 161 of GaInN and barrier layers 162 of GaN, a p-type clad layer 18 of p-type AlGaIn laminated on the p-type clad layer, and a p-type contact layer 19 of p-type GaN laminated on the p-type clad  
5 layer.

In the aforementioned light-emitting device 200, the barrier layers 162 are made substantially uniform in thickness so as to be generally in a range of 70 to 80 Å. Moreover, from the point of view of improvement in color purity, the  
10 intermediate layer 14 of InGaIn is provided, and the n-type clad layer 15 having the same thickness and composition as each of the carrier layers 162 is also formed.

In the background-art group III nitride compound semiconductor light-emitting device such as the aforementioned  
15 light-emitting device 200, or the like, there is a problem in that the effect of confining carriers in the light-emitting layer 16 against the high carrier density n<sup>+</sup> layer 13 is unable to be obtained sufficiently because the thickness of the n-type clad layer 15 under the light-emitting layer 16 is  
20 substantially equal to the thickness of each of the barrier layers 162, and therefore light-emitting efficiency is low in spite of very good color purity.

#### SUMMARY OF THE INVENTION

25 The present invention is designed to solve the aforementioned problem and an object thereof is to provide a light-emitting device of high light intensity by securing the effect of confining carriers in the light-emitting layer

against the high carrier density  $n^+$  layer sufficiently while keeping color purity intact.

Another object of the present invention is to provide a light-emitting device of higher light intensity by the synergistic effect of an n-type clad layer and an intermediate layer according to the present invention to bring the aforementioned carrier confinement effect.

To solve the aforementioned problem, the following means are effective.

That is, a first means, which is applied to a group III nitride compound semiconductor light-emitting device comprising a light-emitting layer of a multilayer quantum well structure composed of alternately laminated well layers and barrier layers, is in that the device further comprises an n-type clad layer which is provided to be in contact with the light-emitting layer and which is made thicker than each of the barrier layers.

A second means, which is applied to the first means, is in that the thickness of the n-type clad layer is set to be not smaller than  $100\text{\AA}$ .

A third means, which is applied to the first means, is in that the thickness of the n-type clad layer is set to be not larger than  $500\text{\AA}$ .

A fourth means, which is applied to any one of the first, second and third means, is in that the device further comprises an intermediate layer which is provided so as to be in contact with a face of the n-type clad layer opposite to the light-emitting layer.

A fifth means, which is applied to any one of the first, second, third and fourth means, is in that the intermediate layer is formed of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 < x < 1$ ).

5 A sixth means, which is applied to any one of the first, second, third and fourth means, is in that the intermediate layer is formed of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0.01 \leq x \leq 0.05$ ).

The aforementioned problem can be solved by the above means.

10 According to the means of the present invention, carriers contributing to light emission can hardly run away from the light-emitting layer 16 toward the high carrier density  $n^+$  layer 13 because the n-type clad layer 15 thicker than each of the carrier layers is formed to be in contact with the light-emitting layer 16 of the multilayer quantum well structure.  
15 That is, the carrier confinement effect can be obtained sufficiently by the n-type clad layer 15, so that light-emitting efficiency is improved.

Further, the thickness of the n-type clad layer 15 is preferably not smaller than  $100\text{\AA}$ , more preferably in a range  
20 of from 150 to  $500\text{\AA}$ . If the thickness is smaller than  $100\text{\AA}$ , it is difficult to confine carriers in the light-emitting layer securely because the thickness is too small. If the thickness is contrariwise larger than  $500\text{\AA}$ , the color purity is worsened. Also from the point of view of productivity, the  
25 thickness of the n-type clad layer 15 is preferably not larger than  $500\text{\AA}$ .

When an intermediate layer is further provided just under the n-type clad layer, a light-emitting device of higher light

intensity can be achieved. GaInN is preferably used as a semiconductor for forming the intermediate layer.

Further, the light emission intensity of the light-emitting device has a strong correlation with the composition ratio  $x$  of indium (In) in the intermediate layer of  $\text{In}_x\text{Ga}_{1-x}\text{N}$ . The light emission intensity of the light-emitting device 100 has an acute peak when the composition ratio  $x$  of indium (In) is about 0.03. Hence, the light-emitting device 100 exhibits high light intensity when  $x$  is in a range of " $0.01 \leq x \leq 0.05$ ".

If the composition ratio  $x$  of indium is smaller than 0.01, the light emission intensity is lowered. If the composition ratio  $x$  of indium is contrariwise larger than 0.05, the crystallinity of the intermediate layer deteriorates because the amount of indium is too large. As a result, semiconductor layers laminated after the intermediate layer cannot be formed with good quality, so that light emission intensity is lowered.

Incidentally, the group III nitride compound semiconductor according to the present invention is represented by the general formula  $\text{Al}_x\text{Ga}_y\text{In}_{1-x-y}\text{N}$  ( $0 \leq x \leq 1$ ,  $0 \leq y \leq 1$ ,  $0 \leq x+y \leq 1$ ), which may further contain group III elements such as boron (B) and thallium (Tl) and in which the nitrogen (N) may be replaced by phosphorus (P), arsenic (As), antimony (Sb) or bismuth (Bi). Accordingly, each of the layers such as the buffer layer, the barrier layers, the well layers, the clad layers, the contact layer, the intermediate layer, the cap layer, etc. in the group III nitride compound semiconductor light-emitting device may be formed of quaternary, ternary or binary  $\text{Al}_x\text{Ga}_y\text{In}_{1-x-y}\text{N}$  ( $0 \leq x \leq 1$ ,  $0 \leq y \leq 1$ ,  $0 \leq x+y \leq 1$ ) of an optional crystal



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mixture ratio such as AlGa<sub>N</sub>, InGa<sub>N</sub>, or the like.

Features and advantages of the invention will be evident from the following detailed description of the preferred embodiments described in conjunction with the attached  
5 drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 shows a typical sectional view showing the  
10 structure of a group III nitride compound semiconductor light-emitting device 100 according to a specific embodiment of the present invention; and

Fig. 2 shows a typical sectional view showing the  
structure of a group III nitride compound semiconductor  
15 light-emitting device 200 according to the conventional art.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described below on the basis of a specific embodiment thereof.

20 Fig. 1 is a typical sectional configuration view of a light-emitting device 100 constituted by group III nitride compound semiconductors formed on a sapphire substrate 11. A buffer layer 12 of aluminum nitride (AlN) about 25 nm thick is provided on the substrate 11. An n<sup>+</sup> layer 13 of a high carrier  
25 density, which is formed of GaN doped with silicon (Si) and which is about 4.0 μm thick, is formed on the buffer layer 12. An intermediate layer 14 of non-doped In<sub>x</sub>Ga<sub>1-x</sub>N (0<x<1) about 3000 Å thick is formed on the high carrier density n<sup>+</sup> layer 13.

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Then, an n-type clad layer 15 of GaN about 250 Å thick is laminated on the intermediate layer 14. A light-emitting layer 16 of a multilayer quantum well structure (MQW), which is constituted by an alternate laminate of well layers 161 of Ga<sub>0.8</sub>In<sub>0.2</sub>N about 30 Å thick each and barrier layers 162 of GaN about 70 Å thick each, is formed on the n-type clad layer 15. The number of the well layers 161 is three. The number of the barrier layers 162 is two. A cap layer 17 of GaN about 70 Å thick is formed on the light-emitting layer 16. A p-type clad layer 18 of p-type Al<sub>0.12</sub>Ga<sub>0.88</sub>N about 300 Å thick is formed on the cap layer. A p-type contact layer 19 of p-type GaN about 100 nm thick is further formed on the p-type clad layer 18.

Further, a light-transparency positive electrode 20A is formed on the p-type contact layer 19 by metal evaporation whereas a negative electrode 20B is formed on the n+ layer 13. The light-transparency positive electrode 20A consists of a cobalt (Co) film about 15 Å thick to be joined to the p-type contact layer 19, and a gold (Au) film about 60 Å thick to be joined to the Co film. The negative electrode 20B consists of a vanadium (V) film about 200 Å thick, and an aluminum (Al) or Al alloy film about 1.8 μm thick. An electrode pad 21 about 1.5 μm thick, which is made of a combination of either Co or Ni, Au and Al or made of an alloy thereof, is formed on a part of the positive electrode 20A.

A method for producing the light-emitting device 100 will be described below.

The light-emitting device 100 was formed by vapor growth in accordance with a metal organic vapor phase epitaxy method

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(hereinafter abbreviated as "MOVPE"). The gasses used were ammonia ( $\text{NH}_3$ ), carrier gas ( $\text{H}_2$ ,  $\text{N}_2$ ), trimethylgallium ( $\text{Ga}(\text{CH}_3)_3$ ) (hereinafter referred to as "TMG"), trimethylaluminum ( $\text{Al}(\text{CH}_3)_3$ ) (hereinafter referred to as "TMA"), trimethylindium ( $\text{In}(\text{CH}_3)_3$ ) (hereinafter referred to as "TMI"), silane ( $\text{SiH}_4$ ), and cyclopentadienylmagnesium ( $\text{Mg}(\text{C}_5\text{H}_5)_2$ ) (hereinafter referred to as "CP<sub>2</sub>Mg").

First, a single-crystal substrate 11 having a face a cleaned by an organic cleaning process as a main face was attached to a susceptor placed in a reaction chamber of an MOVPE system. Then, the substrate 11 was baked at a temperature of 1100°C while  $\text{H}_2$  was introduced into the reaction chamber under normal atmospheric pressure.

Then, the temperature of the substrate 11 was decreased to 400°C and  $\text{H}_2$ ,  $\text{NH}_3$ , and TMA were supplied so that a buffer layer 12 of AlN about 25 nm thick was formed on the substrate 11.

Then, while the temperature of the substrate 11 was kept at 1150°C,  $\text{H}_2$ ,  $\text{NH}_3$ , TMG, and silane were supplied so that a high carrier density  $n^+$  layer 13 of GaN having a film thickness of about 4.0  $\mu\text{m}$  and an electron density of  $2 \times 10^{18} / \text{cm}^3$  was formed.

Then, the temperature of the substrate 11 was decreased to 850°C and either  $\text{N}_2$  or  $\text{H}_2$ ,  $\text{NH}_3$ , TMG and TMI were supplied so that an intermediate layer 14 of  $\text{In}_{0.03}\text{Ga}_{0.97}\text{N}$  about 3000 Å thick was formed.

After the intermediate layer 14 was formed, the temperature of the substrate 11 was kept at 850°C and either  $\text{N}_2$  or  $\text{H}_2$ ,  $\text{NH}_3$ , and TMG was supplied so that an n-type clad layer 15 of GaN about 250 Å thick was formed.

Then, either  $N_2$  or  $H_2$ ,  $NH_3$ , TMG and TMI were supplied so that a well layer 161 of  $Ga_{0.8}In_{0.2}N$  about  $30\text{\AA}$  thick was formed. Then, a barrier layer 162 of GaN about  $70\text{\AA}$  thick was formed in the same condition as used for forming the n-type clad layer

5 15.

Two well layers 161 and one barrier layer 162 were further formed alternately in the same condition as described above to thereby form a light-emitting layer 16 of an MQW structure. A cap layer 17 thicker than  $70\text{\AA}$  was formed on the light-emitting layer 16 in the same condition as used for forming each of the barrier layers 162.

10

Then, the temperature of the substrate 11 was kept at  $1150^\circ\text{C}$  and either  $N_2$  or  $H_2$ ,  $NH_3$ , TMG, TMA and  $CP_2Mg$  were supplied so that a p-type clad layer 18, which was made of p-type  $Al_{0.12}Ga_{0.88}N$  doped with magnesium (Mg) and which was about  $300\text{\AA}$  thick, was formed.

15

Then, the temperature of the substrate 11 was kept at  $1100^\circ\text{C}$  and either  $N_2$  or  $H_2$ ,  $NH_3$ , TMG and  $CP_2Mg$  were supplied so that a p-type contact layer 19, which was made of p-type GaN doped with Mg and which was about  $100\text{ nm}$  thick, was formed.

20

Then, an etching mask was formed on the p-type contact layer 19. After a predetermined region of the mask was removed, the non-masked portion of the p-type contact layer 19, the p-type clad layer 18, the light-emitting layer 16, the intermediate layer 14 and a part of the  $n^+$  layer 13 were etched with a chlorine-containing gas by reactive etching to thereby expose a surface of the  $n^+$  layer 13.

25

Then, a negative electrode 20B for the  $n^+$  layer 13 and

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a light-transparency positive electrode 20A for the p-type contact layer 19 were formed by the following procedure.

(1) After a photo resist was applied, a window was formed in a predetermined region in the exposed face of the n<sup>+</sup> layer 13 by photolithography. After evacuation to a high vacuum of the order of 10<sup>-4</sup> Pa or less, a vanadium (V) film about 200 Å thick and an Al film about 1.8 μm thick were formed by evaporation. Then, the photo resist was removed. As a result, the negative electrode 20B was formed on the exposed face of the n<sup>+</sup> layer 13.

(2) Then, a photo resist was applied onto a surface evenly and then an electrode-forming portion of the photo resist on the p-type contact layer 19 was removed by photolithography so that a window portion was formed.

(3) After evacuation to a high vacuum of the order of 10<sup>-4</sup> Pa or less, a Co film about 15 Å thick was formed on the photo resist and the exposed portion of the p-type contact layer 19 and an Au film about 60 Å thick was further formed on the Co film by an evaporation apparatus.

(4) Then, the sample was taken out from the evaporation apparatus and the Co and Au films deposited on the photo resist were removed by a lift-off method so that the light-transparency positive electrode 20A was formed on the p-type contact layer 19.

(5) Then, to form a bonding-purpose electrode pad 21 on a part of the light-transparency positive electrode 20A, a photo resist was applied evenly and a window was formed in the electrode pad 21-forming portion of the photo resist. Then,

a film about 1.5  $\mu\text{m}$  thick, which was made of a combination of either Co or Ni, Au and Al or made of an alloy thereof, was formed by evaporation. A portion of the film, which was deposited on the photo resist and which was made of a combination of either Co or Ni, Au and Al or made of an alloy thereof, was removed by a lift-off method in the same manner as in the step (4) to thereby form an electrode pad 21.

(6) Then, the atmosphere for the sample was evaluated by a vacuum pump and an O<sub>2</sub> gas was supplied to thereby set a pressure of 3 Pa. In this condition, a process for alloying the p-type contact layer 19 with the positive electrode 20A and a process for alloying the n<sup>+</sup> layer 13 with the negative electrode 20B were performed at an atmospheric temperature of about 550°C by heating for about 3 minutes.

Thus, the light-emitting device 100 was formed.

With respect to a group III nitride compound semiconductor light-emitting device for emitting green light in a main wavelength range of from 510 nm to 530 nm, experiment has shown that relatively high light intensity is exhibited when the thickness of the p-type clad layer 18 is in a range of from 180Å to 500Å. More preferably, the thickness of the p-type clad layer 18 is in an optimum range of from 240Å to 360Å. When the thickness is in the optimum range, the highest light emission output can be obtained.

With respect to a group III nitride compound semiconductor light-emitting device for emitting blue light in a main wavelength range of from 460 nm to 475 nm, experiment has shown that relatively high light intensity is exhibited when

the thickness of the p-type clad layer 18 is in a range of from 90Å to 390Å. More preferably, the thickness of the p-type clad layer 18 is in an optimum range of from 120Å to 300Å. When the thickness is in the optimum range, the highest light emission output can be obtained.

The composition ratio  $x$  of aluminum (Al) in the p-type clad layer 18 made of p-type doped  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  is preferably in a range of from 0.10 to 0.14. If  $x$  is smaller than 0.10, the light emission output is lowered because it is difficult to confine carriers in the light-emitting layer. If  $x$  is larger than 0.14, the light emission output is also lowered because stress applied to the light-emitting layer increases in accordance with the difference between lattice constants of crystals.

Although the above embodiment has shown the case where the light-emitting layer 16 in the light-emitting device 100 has a structure with two MQW cycles, the number of cycles in the light-emitting layer is not particularly limited. That is, the present invention can be applied to a group III nitride compound semiconductor light-emitting device with any number of cycles.

Further, each of layers such as the barrier layers, the well layers, the clad layers, the contact layer, etc. may be made of quaternary, ternary or binary  $\text{Al}_x\text{Ga}_y\text{In}_{1-x-y}\text{N}$  ( $0 \leq x \leq 1$ ,  $0 \leq y \leq 1$ ) of an optional crystal mixture ratio.

Although the above embodiment further has shown the case where Mg is used as p-type impurities, the invention can be applied also to the case where a group II element such as

beryllium (Be), zinc (Zn), or the like, is used as the p-type impurities.

Further, the present invention can be applied to photodetectors as well as light-emitting devices.

5        This invention is not limited to the above description of the mode for carrying out the invention and embodiments thereof at all, and includes various modifications that can be conceived by those skilled in the art without departing from the scope of the claims.

10



WHAT IS CLAIMED IS:

1. A group III nitride compound semiconductor light-emitting device comprising:

a light-emitting layer of a multilayer quantum well structure composed of alternately laminated well layers and barrier layers; and

an n-type clad layer being in contact with said light-emitting layer,

wherein said n-type clad layer is made thicker than each of said barrier layers.

2. A group III nitride compound semiconductor light-emitting device according to claim 1, wherein a thickness of said n-type clad layer is not smaller than 100Å.

3. A group III nitride compound semiconductor light-emitting device according to claim 1, wherein a thickness of said n-type clad layer is not larger than 500Å.

4. A group III nitride compound semiconductor light-emitting device according to claim 1, further comprising an intermediate layer which is provided so as to be in contact with a face of said n-type clad layer opposite to said light-emitting layer.

5. A group III nitride compound semiconductor light-emitting device according to claim 4, wherein said intermediate layer is made of  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 < x < 1$ ).



# ABSTRACT OF THE DISCLOSURE

A buffer layer of aluminum nitride (AlN) about 25 nm thick is provided on a sapphire substrate. An  $n^+$  layer of a high carrier density, which is about 4.0  $\mu\text{m}$  thick and which is made of GaN doped with silicon (Si), is formed on the buffer layer. An intermediate layer of non-doped  $\text{In}_x\text{Ga}_{1-x}\text{N}$  ( $0 < x < 1$ ) about 3000 Å thick is formed on the high carrier density  $n^+$  layer. Then, an n-type clad layer of GaN about 250 Å thick is laminated on the intermediate layer. Further, three well layers of  $\text{Ga}_{0.8}\text{In}_{0.2}\text{N}$  about 30 Å thick each and two barrier layers of GaN about 70 Å thick each are laminated alternately on the n-type clad layer to thereby form a light-emitting layer of a structure with two multilayer quantum well (MQW) cycles.

FIG. 1

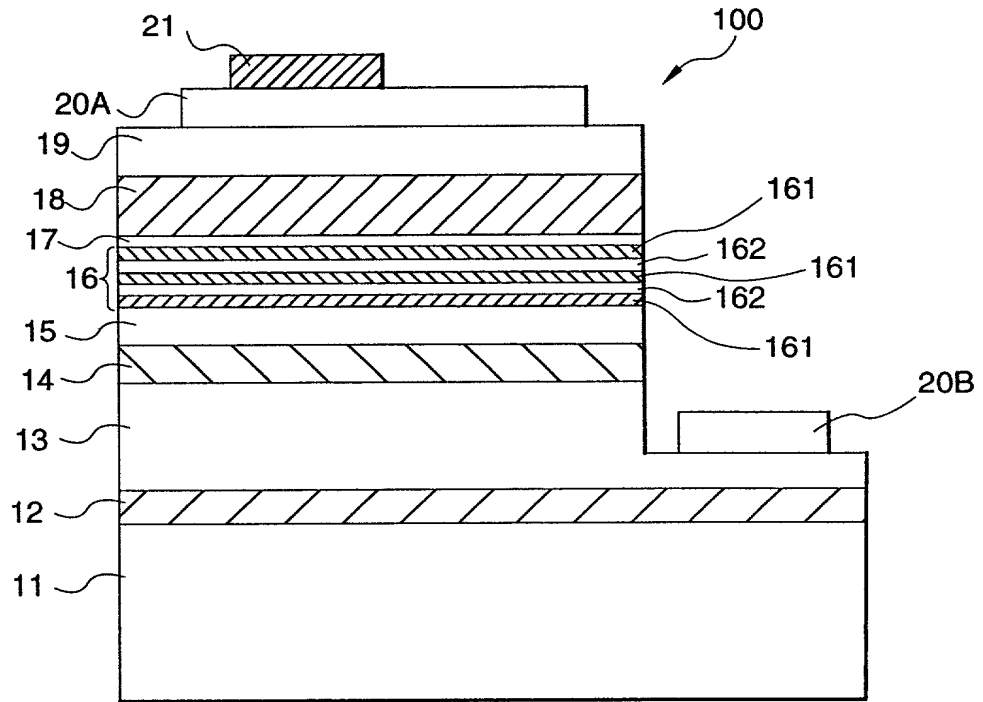
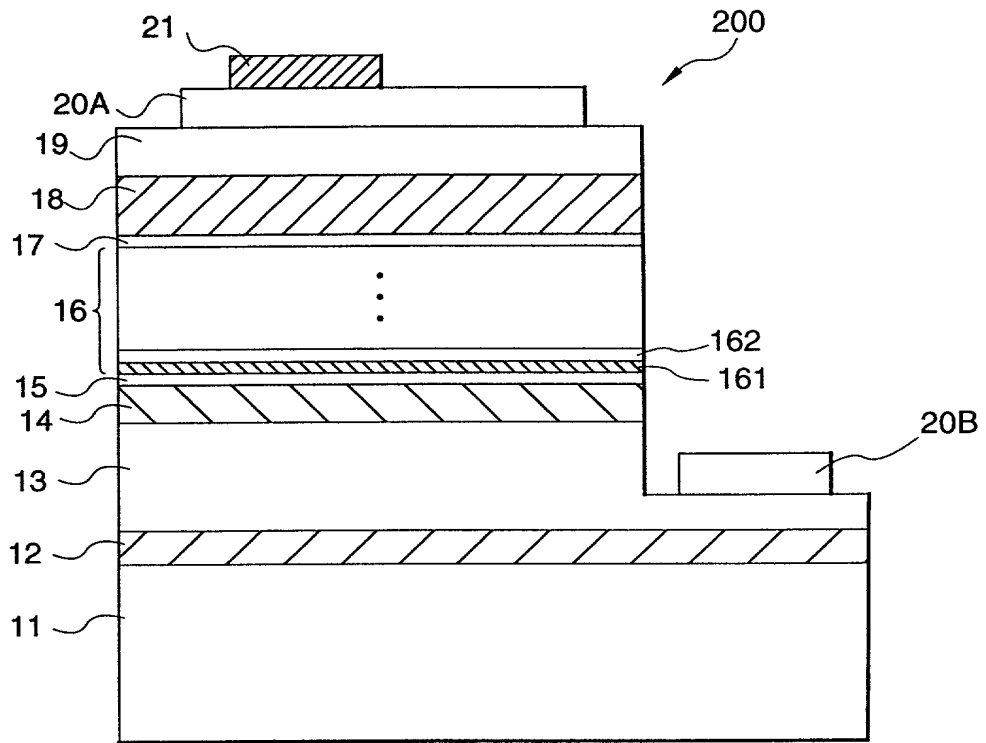


FIG. 2



As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the INVENTION ENTITLED

GROUP III NITRIDE COMPOUND SEMICONDUCTOR LIGHT-EMITTING DEVICE

the specification of which (CHECK applicable BOX(ES))

-> [ X ] is attached hereto.

-> [ ] was filed on \_\_\_\_\_ as U.S. Application No. 0 / \_\_\_\_\_

BOX(ES) -> [ ] was filed as PCT International Application No. PCT/ \_\_\_\_\_ / \_\_\_\_\_ on \_\_\_\_\_

-> -> and (if applicable to U.S. or PCT application) was amended on \_\_\_\_\_

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate filed by me or my assignee disclosing the subject matter claimed in this application and having a filing date (1) before that of the application on which priority is claimed, or (2) if no priority claimed, before the filing date of this application:

PRIOR FOREIGN APPLICATION(S)

Number	Country	Day/MONTH/Year Filed	Date first Laid-open or Published	Date Patented or Granted	Priority Claimed Yes No
P. Hei. 11-090719	Japan	31/March/1999			X

I hereby claim domestic priority benefit under 35 U.S.C. 120/365 of the indicated United States applications listed below and PCT international applications listed above or below and, if this is a continuation-in-part (CIP) application, insofar as the subject matter disclosed and claimed in this application is in addition to that disclosed in such prior applications, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56 which became available between the filing date of each such prior application and the national or PCT international filing date of this application:

PRIOR U.S. PROVISIONAL, NONPROVISIONAL AND/OR PCT APPLICATION(S)

Application No. (series code/serial no.)	Day/MONTH/Year Filed	Status pending, abandoned, patented	Priority Claimed Yes No
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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

And I hereby appoint Cushman Darby & Cushman Intellectual Property Group of Pillsbury Madison & Sutro LLP, 1100 New York Avenue, N.W., Ninth Floor, East Tower, Washington, D.C. 20005-3918, telephone number (202) 861-3000 (to whom all communications are to be directed), and the below-named persons (of the same address) individually and collectively my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent, and I hereby authorize them to delete names/numbers below of persons no longer with their firm and to act and rely on instructions from and communicate directly with the person/assignee/attorney/firm/organization who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented unless/until I instruct the above Firm and/or a below attorney in writing to the contrary.

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